DEVELOPMENT OF A TECHNOLOGY TO PREVENT DEVIATION FROM AN INTENDED LANE WHILE TURNING USING VEHICLE DYNAMICS CONTROL

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ABSTRACT

Active safety technology will become increasingly important in preventing collisions in the future.

The possibility of accidents occurring due to instability in vehicle dynamics leading to deviation from the lane is particularly high when a vehicle enters a corner too fast or is on an icy or snow-covered road, or makes a sudden maneuver to avoid collision with an obstacle during a turn.

To contribute to the solution of this situation, the research described in this paper studies a method of minimizing deviation through optimal control of moment and velocity and then utilizing four-wheel slip control based on estimates of vehicle dynamics.

First, this project studied a system to control deviation from the intended course by providing accurate, real time estimates and control of four-wheel tire gripping forces based on estimates of vehicle dynamics parameters and the road friction coefficient. The method of the vehicle dynamics control utilized in this system was VSA (Vehicle Stability Assist).

Next, the project studied a method of providing comprehensive control. This method utilizes information from the vehicle's navigation system to quantitatively predict the form of a corner before the vehicle enters it. This data is then utilized in combination with VSA to further minimize deviation from the lane.

These two systems were fitted in a test vehicle and tested on snow-covered road surfaces. The results of these tests clearly demonstrate that this system reduces the incidence of deviation from the lane and will therefore be effective in reducing the number of accidents.

1. INTRODUCTION

According to a survey of 2001 Japanese traffic accident data[1], approximately 18% of all traffic deaths were caused by accidents occurring when turning. This means that single or multiple vehicle collisions caused by deviation from the lane account for almost one-fifth of traffic accident fatalities in Japan, as shown in Figure 1.

Figure 2 shows the results of an analysis of the causes of these accidents. Excessive speed and errors in vehicle handling and judgment are the factors behind 59% of fatal accidents occurring when cornering. In other words, almost 60% of fatal cornering accidents are due to driver error.

Extrapolating from these results, it is possible to expect a 10% reduction in fatalities if vehicles are provided with assist systems to compensate for driver errors when turning. The reduction could be even more significant for accidents occurring on icy or snow-covered roads, conditions under which tire gripping force drops dramatically.

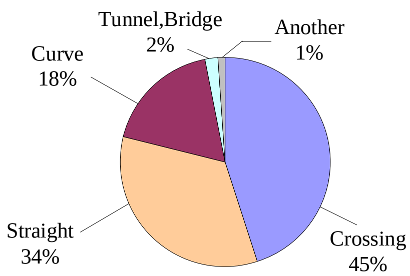

Figure 1. Fatalities in driving accidents (Road environment)

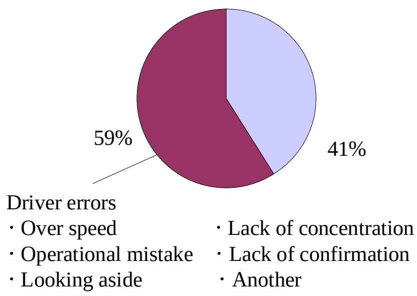

Figure 2. Driving accidents analysis (Driver errors)

2. Research Goal

The results of the analysis discussed in Section 1 indicate that controlling deviation from the lane when turning will enable vehicles collisions with objects to be avoided, therefore reducing the number of traffic accident fatalities.

The project discussed here targets, in particular, the minimization of deviation from the intended course when turning on icy or snow-covered road surfaces.

The project studied two methods for the prevention of deviation from the lane in the following order:

(1) A method of controlling deviation utilizing VSA.

(2) A method of preventing deviation from the intended course before it occurs utilizing VSA in combination with advance data on the form of the corner received from the vehicle navigation system.

It was the goal of this study to test these methods in an actual vehicle, analyze their effectiveness, and clarify a future research agenda.

3. Basic Principles

This section will discuss the basic principles of the two methods.

3.1 Prevention of Deviation from the Lane Using VSA

As Figure 3 shows, this method enables early detection of under steer (US) during cornering by calculating four-wheel tire gripping forces in real time with a high degree of accuracy using vehicle dynamics parameters[2] and the road friction coefficient(road μ) estimation[3] logic. Deviation from the intended course is prevented by the operation of deceleration control and moment control[4] to reduce US. As can be seen from Figure 3, control to prevent deviation goes into operation after the turn has commenced. Control is applied by an engine torque control actuator and an active hydraulic brake modulator unit.

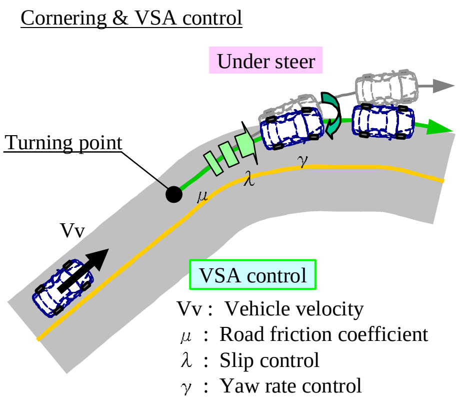

Figure 3. US control with VSA

3.2 Prevention of Deviation from the Lane Combining the Navigation and VSA Systems

Figure 4 shows an image of the application of control using information from the navigation system in combination with VSA. In this method, deviation from the intended course is prevented by earlier operation of deceleration control and VSA control on the basis of calculation of the position of commencement and curvature (or turning radius) of an upcoming corner using data from the vehicle navigation system. Control is applied as necessary before the vehicle begins to turn.

In addition, after the vehicle commences turning, deviation is continuously monitored and controlled with optimal application of deceleration control using VSA control as necessary to correct vehicle stability.

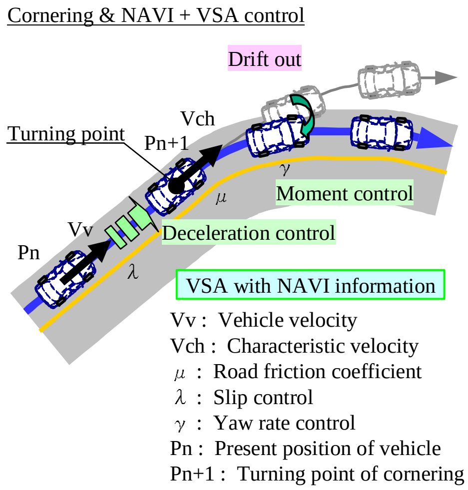

Figure 4. Lane trace control with NAVI+VSA

4. Control Logic

This section discusses the configuration of each system and the logic they utilize.

4.1 VSA System

(1) System Configuration

The configuration of the VSA system is shown in Figure 5.

The system utilizes wheel velocity sensors for each wheel, a steering wheel angle sensor, longitudinal and lateral acceleration sensors and a yaw rate sensor. The control actuator is made up of an active hydraulic control brake unit and an FI control unit.

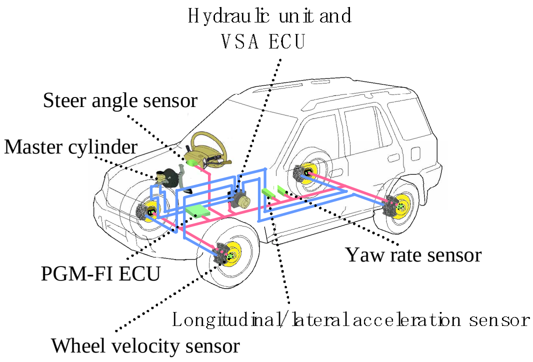

Figure 5. Configuration of VSA

(2) Control Logic

As Figure 6 shows, the system sequentially estimates tire gripping force and road μ. When the vehicle enters a turning mode (when the driver commences turning the steering wheel), the system calculates nominal yaw rate from the amount of steering angle and vehicle velocity, and can make an early judgment on US (indicating deviation from the intended course) by comparing values from the sensor with calculated values. The degree of US is estimated and optimal control of slip is provided in response to the estimated tire gripping force for each wheel. This system minimizes deviation from the intended course by providing deceleration control to the two rear wheels and moment control mainly to the front inner wheel.

However, because it cannot determine the intended course, this method can only judge deviation from the course on the basis of driver steering input and vehicle yaw rate. The method therefore displays fixed technical limits in terms of the quantitative estimation of deviation from the lane and the accurate application of control.

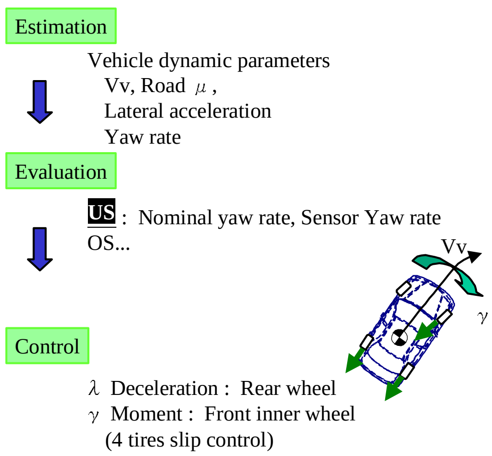

Figure 6. VSA control logic

4.2 VSA in Combination with the Navigation System

(1) System Configuration

Figure 7 shows the configuration of this system which adds the navigation system and a data processing ECU to the VSA system discussed in the preceding section. This ECU calculates the trajectory of the intended course from the vehicle's present position and the curvature (or radius) of an upcoming corner using signals from the navigation system and transmits this data to the VSA system. It should be noted that for the navigation system used in this research, the error for the estimated turning radius was $\pm$10%.

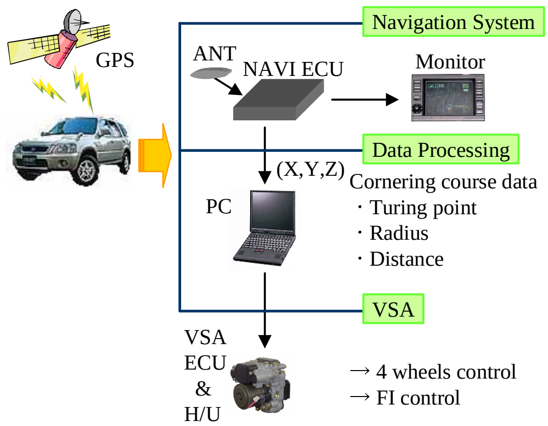

Figure 7. Configuration of NAVI+VSA system

(2) Control Logic

Quantitative prediction of deviation from the lane is difficult to achieve using VSA alone. The VSA system was therefore supplemented with external data concerning the form of the road. As shown in Figure 8, the system uses data from the navigation system to calculate the position of commencement and the curvature and radius of an upcoming corner. Then it applies control based on a quantitative prediction of the amount of deviation utilizing the vehicle's present position, velocity and the road μ.

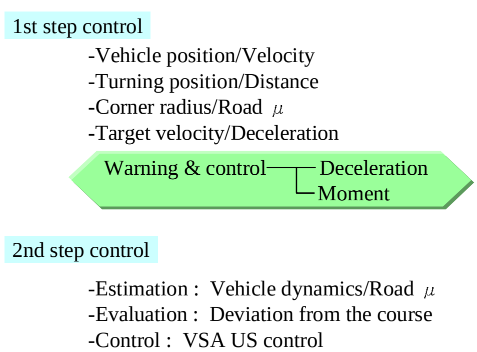

Figure 8. NAVI+VSA control logic

Application of control is divided into two steps:

In the first control step, data is received from the navigation system concerning the position of commencement and the turning radius of an upcoming corner. With this data as a basis, the critical safety velocity at the commencement of the corner is calculated from vehicle dynamics parameters and road μ. Deceleration and yaw rate control are applied to stably bring the vehicle to the target velocity and yaw rate.

In the second control step, if the system judges that insufficient control has been applied up to the commencement of the corner and deviation from the intended course will occur, the extent of deviation is sequentially quantitatively calculated, and deceleration control, VSA control, and minimum stopping distance braking control are selectively applied in response.

In basic terms, this enables deviation from the lane to be prevented by application of deceleration control and VSA control before the corner is entered. In addition, the system makes it possible to respond to changes such as sudden avoidance maneuvers made by the driver and changes in road surface conditions and to maintain a stable trace until the corner is exited.

5. Test Results

This section discusses the results obtained from vehicle tests.

5.1 Results of Tests of Prevention of Deviation Using VSA

(1) Test Course and Driving Mode

As shown in Figure 9, the test course was a snow-covered 50m-radius J turn course. The initial vehicle speed was 50km/h and the maneuver is driven by a closed loop steering input.

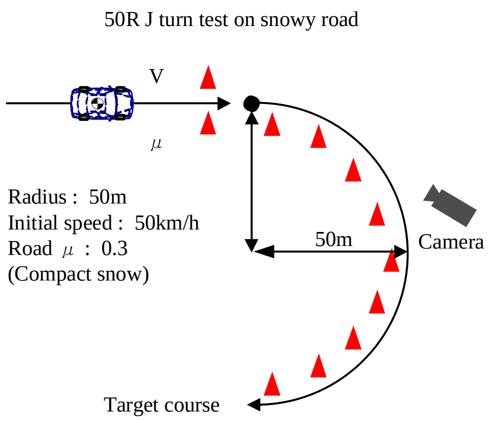

Figure 9. VSA test course

(2) Results of Tests Without Operation of VSA

Figure 10 shows typical results of tests conducted without VSA in operation. In these photographs, the vehicle enters the corner at excessive speed and deviates outside the 3.6m width of the test course due to insufficient tire gripping force and initial under steer.

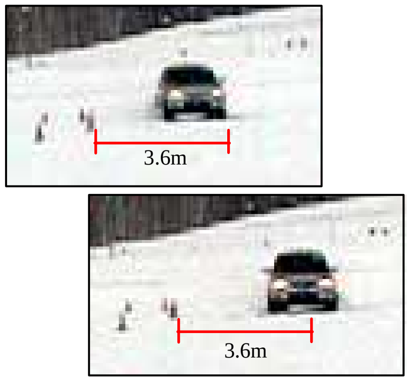

Figure 10. Test scene without VSA

(3) Results of Tests Using VSA

The VSA system enables early judgment of US from the steering input when a corner is entered thus allowing the application of deceleration control and moment control.

The photographs in Figure 11 show that the operation of VSA enables a higher level of control over deviation from the intended course than can be attained when the system is not in operation.

However, deviation does occur to some extent in the period between the detection of US and the control taking effect. It is impossible for the system to completely prevent this deviation.

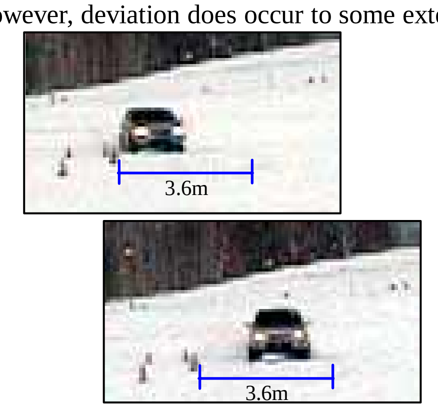

Figure 11. Test scene with VSA

Figure 12 shows time series test data obtained in tests conducted with and without VSA in operation. The data shown here indicates that when VSA control is in operation, vehicle yaw rate demonstrates a linear response to steering.

In contrast, when no control is applied, yaw rate response is delayed and gain is low, resulting in a larger deviation from the intended course.

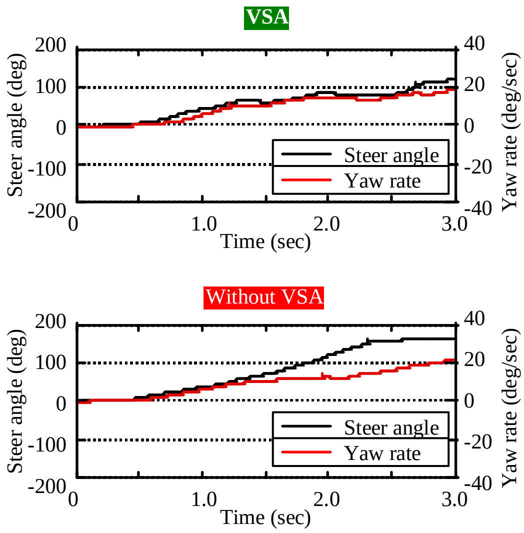

Figure 12. Test data graph of VSA

5.2 Results of Deviation Prevention Tests Using the Navigation System in Combination with VSA

(1) Test Course and Driving Mode

As Figure 13 shows, these tests utilized a corner on a snow-covered winding course previously recorded in the vehicle navigation system. The course featured a down slope S-bent of a right-turn corner of 80R and a left-turn corner of 80R. The initial vehicle speed was 70km/h, and the steering input was closed loop.

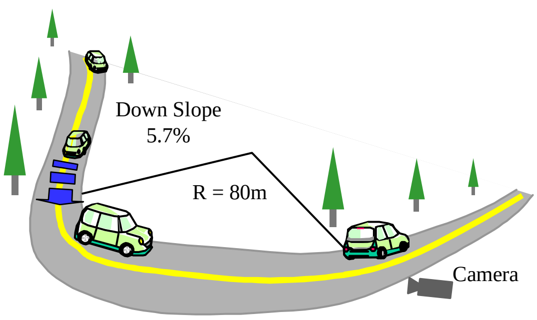

Figure 13. NAVI+VSA test course

(2) Results of Tests Without Operation of the Navigation System

Because the initial vehicle speed was 20km/h or more higher than the speed which would allow the turn to be negotiated, the level of initial under steer was high and the vehicle deviated more than 1m from the course width of 3.6m despite VSA operation. See Figure 14.

It can be seen from this photograph that VSA alone cannot provide a sufficient level of control to prevent deviation from the intended course.

(3) Results of Tests Using the Navigation System

In these tests, it was possible to apply early deceleration control up to the point of

Figure 14. Test scene with VSA

commencement of the turn in order to bring the vehicle to target velocity of 50km/h. This was accomplished using course data obtained from the navigation system 50m before entering the corner. As the photograph in Figure 15 shows, this enabled stable turning with no deviation from the intended course.

Even when the initial speed was increased, it was possible to control deviation to within the course width of 3.6m by continuous application of stronger deceleration control and VSA control during turning.

Figure 15. Test scene with NAVI+VSA

For reference, Figure 16 shows the setup of the combined navigation and VSA systems as used in the test vehicle.

When the system judges that the speed of

Figure 16. Operating scene of equipped system

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approach to the corner is too high, a warning lamp flashes and a warning alarm is sounded. If the steering response made by the driver is inappropriate, the VSA system engages deceleration control and, if necessary, US control.

As the time series data in Figure 17 demonstrates, the use of the navigation system data enables judgment of the situation and the application of control with a sufficient margin of time and distance before the corner is reached.

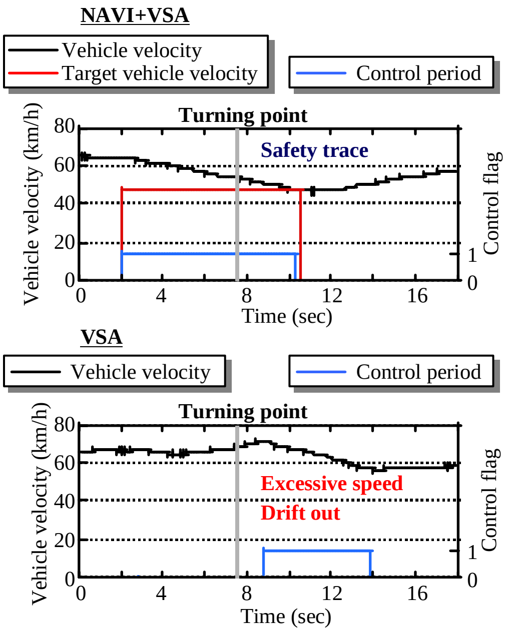

Figure 17. Test data graph of NAVI+VSA

6. Discussion

This section will consider the effectiveness of control based on the test results just discussed.

6.1 Effectiveness of VSA Control

In the test mode utilized in this study, VSA control reduced deviation, confirming its effectiveness. However, because the system itself is incapable of quantitatively calculating the amount of deviation, there are limitations on the control it can apply. In addition, because the system cannot predict deviation before a corner is entered, it cannot prevent deviation by prior application of control.

This study has therefore determined that it would be difficult for a vehicle dynamics control system alone to achieve the target reduction in accidents caused by deviation from the intended course.

6.2 Effectiveness of Combining Navigation System Data with the VSA System

Utilization of navigation system data in combination with VSA control enables control to be applied with an appropriate margin of time and distance before the corner is entered. It is therefore possible to decelerate sufficiently to maintain a stable line trace before commencing a turn.

In addition, if changes in road μ or sudden steering input create a situation which requires further response in addition to the initial deceleration control, the system can quantitatively predict the extent of deviation from the intended course by combining sequential real time estimates of vehicle dynamics and road μ with navigation system data. This makes it possible to stably trace the intended course even in full turning mode, therefore minimizing the extent of deviation.

7. CONCLUSION

The study discussed in this paper enabled the following conclusions to be drawn:

(1) It is possible to quantitatively estimate the amount of deviation from the intended course using navigation system data and to use these estimates to supplement vehicle dynamics control systems.

(2) This study determined that this combination was effective in reducing the amount of deviation against the standalone VSA system.

(3) Further improvements in the accuracy of the position detection function of the navigation system will enable improved prevention of deviation and increased reliability.

As for the future research agenda, in combination with real time estimation of road μ, the ability to preview road μ in advance using data obtained from cameras or Information System will further increase the reliability and responsiveness of the system.

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